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# A Modern 132 kV. Transformer.

By R. M. CHARLEY, M.C., B.Sc, M.I.E.E., Mem.A.I.E.E.

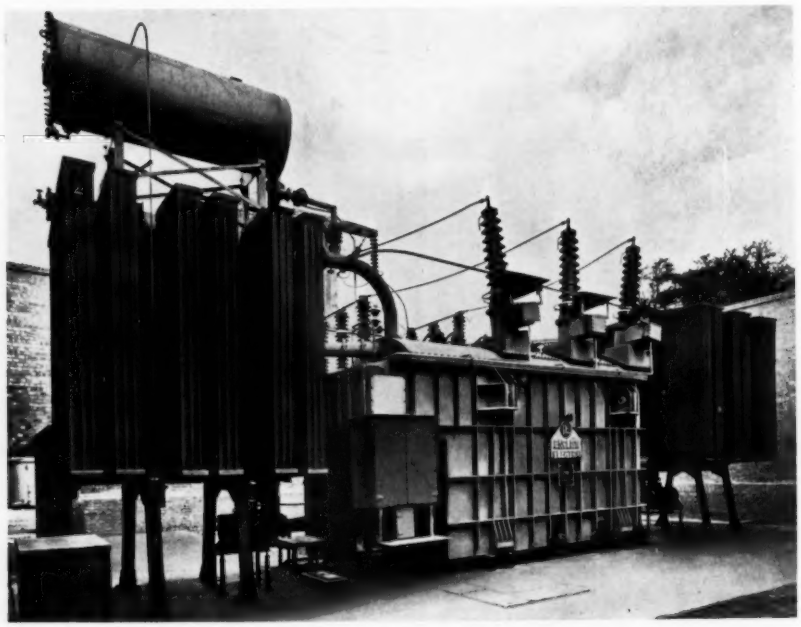

*Fig.* 1.—*A* 30,000 *kVA.*, 132-*kV.* "*English Electric*" *Transformer supplied to the Central Electricity Board.*

Since the inception of the Central Electricity Board our country has been covered by a vast network of transmission lines for operating pressures of 132 kV., 66 kV. and 33 kV. By means of this "Grid," existing and new power stations have been coupled together for transfer of power in large bulk at 132 kV. or 66 kV., and many secondary distribution systems have been arranged for pressures of 66 kV. or 33 kV., while in some cases individual supplies have been given at 132 kV. It is an interesting fact that the total capacity of transformers ordered by the Central Electricity Board to date is over 12 million kVA., of which 9 million kVA. is for service at 132 kV., and 3 million kVA. is for service at 66 kV. or lower voltages.

In the original scheme, known as the Central Scotland Scheme, the largest three-phase unit was 30,000 kVA., and for the higher capacities banks of single-phase units were installed. The factor that determined this policy was the requirement that all transformers should be capable of transport from manufacturers' works to site in their own tanks filled with oil on available rail wagons. It was soon realised that there was no difficulty in building much larger three-phase units and that suitable rail and road vehicles could be produced, and consequently no time was

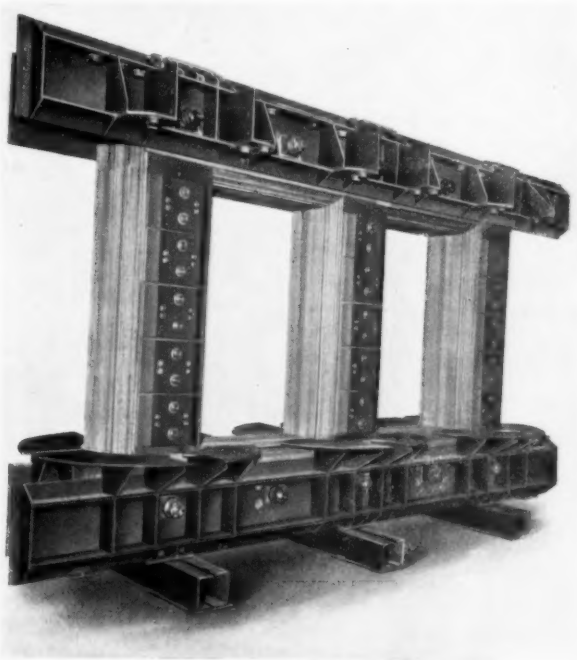

*Fig. 2.—Core assembled with main frames.*

lost in building such vehicles capable of carrying a load of 120 tons, which enabled transformers of 75,000 kVA. at 132 kV. to be built as three-phase units and delivered to site without there being any necessity for drying out on site. Since that time only three-phase units have been installed.

In the Central Scotland Scheme, the largest ON transformer was of 10,000 kVA. output, the larger sizes were provided with OB (air-blast) cooling or forced-oil circulation coupled with air-blast (OFB) cooling, but in each case the transformer was capable of carrying half-load without the aid of the auxiliary cooling plant. Later, the size for which ON cooling was adopted increased greatly and units of 30,000 kVA. have been installed on the Grid, while for other purposes units of 40,000 kVA. have been built.

All transformers except for capacities below 2,000 kVA. installed by the Central Electricity Board have been provided with on-load tap-changing equipment, which has given satisfactory service and has vindicated the original policy for its adoption as compared with the alternative scheme involving separate booster-transformer regulators.

The vast increase in the demand for electricity for industrial purposes has taxed the Grid very severely, and perhaps the time is near when, for transmission of power in the larger bulk required, much higher transmission pressures will be necessary. When this demand arises, manufacturers are ready to build suitable transformers.

The following text and illustrations describe a typical 30,000 kVA. 132 kV. transformer of the Company's manufacture (see Fig. 1).

It is a three-phase unit of the core type and is provided with ON/OFN cooling. Its voltage ratio is 132/33 kV., the connections being Star/Delta. On-load tap-changing equipment is provided on the H.V. winding for a range of 20 per cent. in fourteen steps.

Details of the core construction are shown in Fig. 2. The core is built with three limbs and the yoke and limb laminations are interlaced. The design of a large core demands great care from the mechanical, thermal and magnetic points of view, and the Company's method of construction embodies the best possible features in all these respects. The limbs are clamped with but a single row of insulated bolts with separate clamping plates. The top and bottom yokes are clamped between frames of built-up welded construction designed to give the necessary strength for this purpose and also for the adequate support of the windings, at the same time giving the minimum obstruction to the circulation of oil and adequate clearance for leads from the inner windings. These frames are bolted to the yokes by means of five heavy insulated bolts. The core is carried in a cradle comprising three saddles which bridge the lower main frames; three similar saddles are located above the top main frames; top and bottom saddles are connected together by tie-bolts which pass down along the face of the limbs inside the windings. A lifting-beam is bolted to the top saddles. In this manner the complete core and windings is lifted without any strains being applied to any part of the laminated structure of the core. In order to ensure that the innermost parts of the core do not exceed a reasonable temperature, cooling ducts are provided in a special manner. Short slots are punched in the laminations of the limbs in varying positions so that when the core is assembled, the duct passes through the core from side to side in a series of steps. This method of cooling is most effective, for the cooling oil passes the edges of the laminations in the hottest parts and it does not require any inactive space in the core. Both these features are of great benefit as compared with designs in which cooling ducts are provided merely by spacing the laminations at a few points across the core.

The H.V. and L.V. windings are arranged in a double concentric manner, the L.V. winding being placed between two sections of the H.V. winding. The H.V. neutral is solidly grounded, and for this reason the adjacent portion of the H.V. winding is located near the core limb and

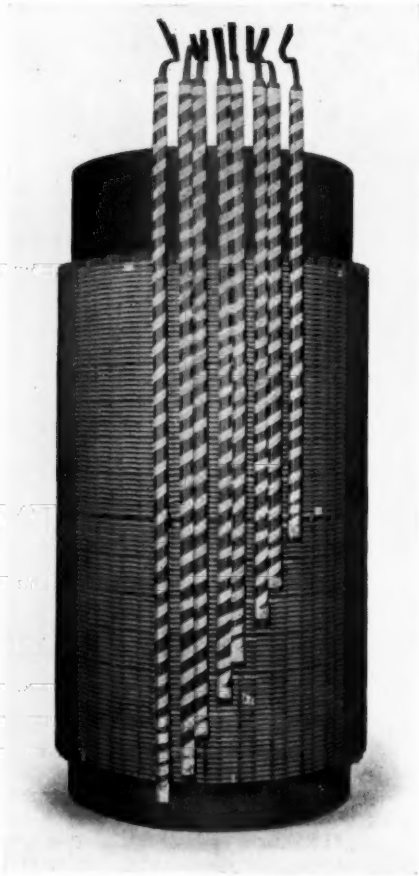

*Fig. 3.—Winding for connection to on-load tap-changing equipment.*

the line end is mounted on the outside of the L.V. winding with the line lead at the top of the column. The portion of the H.V. winding used for obtaining the 20 per cent. voltage range by means of the on-load tap-changing equipment is connected electrically adjacent to the reinforced turns at the neutral end of the winding and it comprises a continuous disc spiral coil formed on a bakelised-paper cylinder of the same equivalent length as the H.V. and L.V. windings, and is wound in two parallel axial sections, so that for each tapping a portion of winding is taken out equally on both sides of the centre. The tapping leads are brought vertically up through oil ducts on the outside of the coil and are encased in channels of fullerboard, as shown in Fig. 3. This arrangement ensures that for every tapping the displacement between the magnetic centres of the H.V. and L.V. windings is extremely small and consequently the vertical mechanical forces produced under short-circuit conditions are a minimum. The importance of this feature cannot be over-emphasised, for the reliability of a transformer is determined as much by its strength to resist the mechanical forces that arise under short-circuit conditions as by its capability of withstanding the electrical stresses that occur due to surges on the system.

Paper-insulated wires are used throughout the windings, and all joints between coils and sections are wrapped to give equivalent electrical strength. The arrangement of insulation between coils and turns is carefully proportioned in order to ensure that the transformer will withstand the surge conditions normally experienced in service.

Both H.V. and L.V. windings are formed of columns of double-section disc coils, oil ducts being formed between adjacent sections by means of fullerboard sectors. The main insulation between H.V. and L.V. windings is comprised of cylinders of fullerboard separated by oil ducts formed by axial spacers of the same material. Care is taken in the disposition of spacers and oil ducts to ensure that the circulation of oil will avoid excessive local heating and will result in the average temperature gradient between the copper and oil being as low as possible. This same feature coupled with the determination of the proportions of the conductor ensures that no distortion of the individual portions of the winding can occur under short-circuit conditions.

The windings are clamped by steel rings, split at one point, placed on the top of each column and pressure is applied by means of substantial studs mounted in the top main frames. After the shrinkage process has been applied to the windings, a reasonable pressure is applied by means of the clamping arrangement, and it is extremely improbable that any slackness will ever occur in the windings.

The tapping leads on the spiral coil described above are connected to flexible paper-wrapped cable and are brought through large tubes of bakelised-paper rigidly supported on the top main frames to one end, for connection to the on-load tap-changing equipment. The complete core and windings are illustrated in Fig. 4.

The H.V. line leads are brought out through condenser bushings protected with porcelain rain shields and mounted in turrets on the main tank cover. The bushing is formed on a metal tube and the lead from the winding on the form of a flexible cable passes through this tube to the cap of the bushing from which it can be easily detached. This arrangement allows for the removal of a bushing without it being necessary to gain access to the main tank to disconnect the lead.

Current transformers either one or two per phase are mounted in the H.V. bushing turrets, the secondary leads being taken to weatherproof terminal boxes located on the side of the turrets.

Single-piece oil-filled porcelain bushings are used on the L.V. side. There are two bushings for each phase; one end of each phase of the winding is connected to a bushing while the other

end is taken to a link board located at one end of the tank and accessible through a handhole. Interphase connections can thus be selected, the Delta connection being completed externally by joining the bushings together in pairs, so that the vector relationship between the H.V. and L.V. windings can be changed from 30° lead to 30° lag, i.e., 42 Y d 11 to 32 Y d 1.

The tank is constructed of heavy boiler plate reinforced along the long sides with stiffeners which form a large number of panels ; this design is effective in limiting vibration of the tank side and hence in reducing noise. A substantial underbase is welded to the tank bottom. Jacking lugs are mounted at the bottom of the tank sides and at the top are located further lugs so that the transformer can be carried on the girders of the railway wagons provided for the heaviest loads, and in these lugs are trunnions by means of which the transformer is lifted by cranes in the manufacturer's works. The cover is arched and is bolted to the tank flange by a large number of bolts.

Cooling surface to dissipate the heat generated by the losses of the transformer is provided by a number of tubular radiators arranged in two banks, one at each end of the tank. Each radiator is built up of a large number of elliptical tubes welded into headers at each end ; these are connected at top and bottom to main headers, which are coupled to the main tank through large-diameter pipes in which main shut-off valves are inserted. Between each radiator and the header is located a simple valve so that any radiator may be removed with the minimum disturbance to the oil and cooler structure. The main headers are mounted on a structure which gives rigid support and on one of these structures the expansion vessel is supported. The expansion vessel has a detachable end-cover, and a magnetic-type float-operated oil-level gauge. In the pipe between the main tank and the expansion vessel is a double-float Buchholz protective device.

In the lower main pipe of each cooler through which the cooled oil returns to the main tank is located a motor-driven pump of the impellor type. The control gear for these motors is housed in a weatherproof cubicle near the transformer. They are brought into operation or shut-down automatically, depending on the load on the transformer as indicated by the winding temperature indicator described later. When the pumps are not running the coolers are capable of dissipating the losses corresponding to half-load on the transformer, or alternatively, it will carry half-load if one cooler is shut off and the pump of the other cooler is running.

For temperature indication two dial-type thermometers are located in the cooler-control cubicle and are connected by means of capillary tubing to bulbs inserted in the transformer cover. One indicates the oil temperature and the other the temperature of the windings. The latter measures the winding temperature indirectly ; a heating-coil is calibrated to have the same temperature gradient as the transformer winding ; it is supplied with current from the secondary of a current transformer connected in series with the main winding and is located in the hottest oil ; the thermometer bulb is inserted inside this coil. Thus the indicator follows the actual temperature of the main winding with a negligible time lag.

Each thermometer is provided with contacts which make or break electrical circuits when pre-determined temperatures are reached. An alarm is given when the oil temperature reaches an unduly high value. One contact on the winding temperature indicator is used to trip the main circuit breaker at a temperature that would cause damage to the winding if it were maintained for a long period. The other contacts on this thermometer are used to start up or shut down the cooler-pump motors, as referred to above.

The on-load tap-changing equipment is mounted at one end of the main tank and does not have to be removed when the transformer is prepared for transport by road or rail. The scheme employed is the mid-point auto-transformer arrangement which has the advantage that

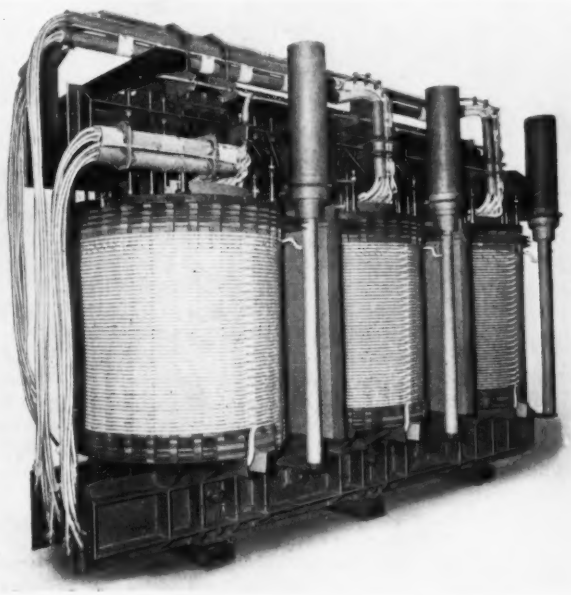

*Fig. 4.—Completely assembled core and windings.*

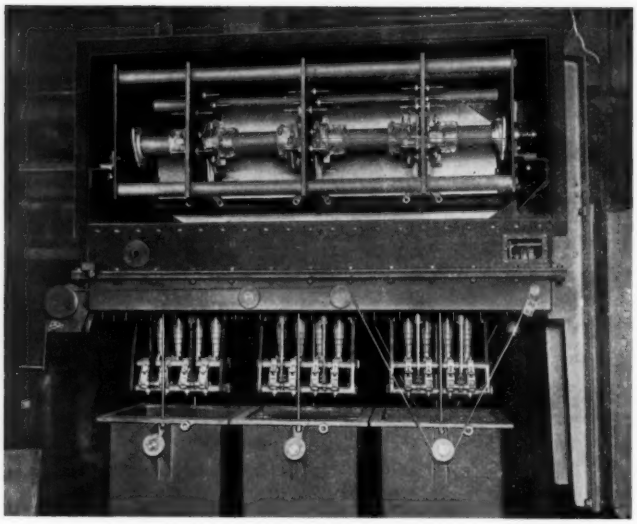

*Fig. 5.—On-load tap-changing gear showing the selector switch and divertor-contactors.*

the number of tappings on the main winding corresponds to half the number of voltages required, thus allowing the transformer itself to be as simple and reliable as it is possible to make it, and the various parts of the gear are rated so that even if the time occupied for a tap-change process is unduly prolonged from external causes, no damage to the transformer or the tap-changing gear can result. An important feature of the mechanical arrangement of the tap-changing equipment is that it is entirely external to the main transformer tank and that there is no communication for oil between the main tank and the chambers in which electrical circuits are made and broken. It is recognised that a certain amount of maintenance is necessary and great attention has been paid to facilitating this being done.

As described above, the tappings from the voltage regulating winding are brought through paper-insulated flexible cable to one end of the core and windings where they are connected to the stalks of three multiple bushings mounted in the tank wall. This end of the main tank is built to form a pocket in which the mid-point auto transformers are located.

The tap-changing gear proper is divided into two main parts : (i) the selector switch, and (ii) the divertor-contactors (see Fig. 5).

The selector switch is mounted in a chamber bolted to the pocket of the main tank mentioned above. It comprises the switches for all three phases mounted in line, the moving contacts being assembled on a large-diameter bakelised-paper tube supported in bearings at each end, and the fixed contacts being arranged in vertical bakelised-paper boards. The fixed contact studs project on both sides of a board and the moving contacts, two per phase, are slightly staggered so that they can either rest on the same stud or touch adjacent studs ; the former position corresponds to the mid-point auto-transformer having both ends connected to the same tapping on the main winding, in other words it is short-circuited, and in the latter position the mid-point auto-transformer is connected across a pair of tappings and the voltage resulting is that corresponding to mid-way between these two tappings. The moving contact comprises a heavy spring-loaded segment. Current is taken from these contacts to the mid-point auto-transformer through spring-loaded copper brush-blocks, which make contact on edge-wise slip rings fixed to the selector-switch shaft. The whole of the selector-switch mechanism is mounted on a frame separate from the chamber so that it can be withdrawn as a whole if necessity arises. The selector-switch shaft is rotated step by step by a Geneva wheel motion driven by a crank and bevel gearing from the main operating mechanism.

Connections from the selector switch and mid-point auto-transformer to the divertor-contactors are made through condenser bushings fixed in the floor of the selector-switch chamber. There is a pair of divertor contactors for each phase, mounted in a separate tank bolted to the underside of the selector-switch chamber, and arranged with rope lowering gear so that each tank can be lowered separately without draining off any oil, thus greatly facilitating inspection and maintenance. The divertor-contactors of all three phases are operated by the same cam through two sets of toggles, the cam making half a revolution for a tap-change process. The cam is double acting and although a spring arrangement assists the quick opening of the contacts, the cam ensures the complete opening in the event of failure of a spring.

When a tap-change process is initiated the mechanism first causes one divertor-contactor to open, then the selector switch moves forward one step so that the corresponding moving contact moves to the next fixed-contact stud, while the other moving-contact does not leave the stud on which it rested, then the divertor-contactor is closed. For a second tap-change in the same direction, the other divertor-contactor opens and is followed by the appropriate movement of the selector switch, and closing of the divertor-contactor. The whole sequence of operations is determined very positively by the motor-operating mechanism, and is such that the really

active part of the cycle occupies only about one-third of the whole.

The motor-operating mechanism is assembled in a weatherproof cubicle permanently fixed at the end of the selector-switch chamber, and readily accessible from a platform. A three-phase squirrel-cage motor drives the worm shaft of a reduction gear through a friction clutch which is part of an electro-magnetic brake, and the worm wheel-shaft of the reduction gear drives the tap-changing gear. The coil of the brake is connected across two of the motor terminals, and its function is to bring the mechanism to rest quickly as soon as the motor circuit is interrupted at the end of a tap-change process. Also on this shaft is a small roller crank which operates a Geneva wheel which drives an auxiliary shaft on which are mounted the gear for mechanical tap-position indication limit switches, auxiliary selector switch for remote tap-position indication and, if required, another auxiliary switch for supervisory control. On the main operating shaft is the retaining switch, by means of which the control circuits are completed locally so that independently of the operator, the tap-change process, once it is initiated, must be completed.

The motor circuit is controlled by " raise " and " lower " contactors, across the contacts of which are connected metal rectifiers, and by a triple-pole thermal cut-out. The cubicle is provided with a heater which prevents condensation in the mechanism in cold or damp weather. Underneath the cubicle is a small box in which is located the push-button and control selector switch for local control. By means of a dog clutch in the main operating shaft the motor-driving mechanism is disengaged and an interlocking slide uncovers the end of a lay-shaft, thus allowing a crank handle to be inserted and a tap-change process can then be carried out by making one smart continuous revolution. The interlocking mechanism makes it quite impossible for the motor drive to be re-engaged until the handle is removed. A mechanically-operated counting device is provided ; it records all tap-change processes, whether made by hand or electrically.

The remote control equipment for the on-load tap-changing gear is mounted in the control room on the panel for the associated switchgear. It comprises " raise " and " lower " push-buttons, a tap-position indicator, a warning buzzer and lamp. After a push-button is depressed, the circuit is completed through the retaining switch, and the buzzer and lamp indicate that the push-button may be released. When operating from this control panel it must be ascertained that the control selector switch in the local control box underneath the motor-operating mechanism cubicle is in the position for remote control. The tap-position indicator is a simple and interesting instrument. It has two fixed coils and two high resistances, all connected in series across the operating supply mains. The moving element comprises a small iron armature and one coil, a pointer being fixed in line with the axis of the armature. Current is taken to the moving coil by means of two ligaments ; one end is connected to the mid-point of the fixed field system, and the other end is taken through a high resistance to the switch arm of the selector or transmitter switch mounted in the motor-operating gear. When the circuit is energised the fixed coils exert a force on the iron armature, tending to keep the pointer in the mid-position on the scale ; if the transmitter switch is in the mid-position no current can pass through the moving coil, and hence the pointer is influenced only by the control iron of the armature, and remains in the mid-position ; if the transmitter switch moves to another contact, current will flow in one direction or the other through the moving coil, thus causing a torque which will deflect the pointer. The deflecting torque on the moving coil, and the restraining torque on the armature are equally affected by any change in the supply pressure, and hence the accuracy of the indicator is independent of all normal voltage variations. In the event of failure of the control supply, the pointer falls off the scale to a position marked " off."

A Klaxon and lamp are arranged to give warning from the upper float of the Buchholz protective device, from the thermometer for indicating the oil temperature and the auxiliary contacts of the protective cut-outs on the cooler-pump motors, flag indicators are provided for each device. The Klaxon can be de-energised by resetting its check alarm relay, which leaves the lamp alight until the flag indicator is reset.

An auxiliary transformer is installed in order to provide a neutral for the L.V. system and to give a local supply at 400 volts. Its primary winding is inter-star connected and the neutral is brought out for connection to a resistance designed to limit the earth fault current to 750 amperes, which the transformer winding is capable of withstanding for 30 seconds. The secondary winding is star-connected and is designed to give 130 kVA. at 400 volts for station auxiliary circuits. The tank is provided with expansion vessel, silica-gel breather and single-float Buchholz device with alarm contacts.

# Fundamental Requirements in the Erection of Steam Turbine-Driven Generating Units.

By R. H. KEEN,
Engineer-in charge, Outside Department, Rugby.

The erection, adjustment and setting to work of modern Steam Turbine Generating Units provides many problems for the Erecting Engineer, and many running and maintenance troubles can be avoided by skilful erection and careful attention to certain fundamental requirements during the initial installation.

It is the purpose of this article to consider such of these requirements as in the author's opinion contribute most directly to the satisfactory operation of the plant, it having been his experience that on modern well-proved designs more running troubles arise from maladjustment than from faulty design or material. These inaccuracies in adjustment may be due to manufacturing errors, faulty setting during erection or changes in the original setting from causes arising during operation or after the plant has been commissioned, but it is only proposed to deal here with matters arising during the actual erection process.

It will be seen, therefore, that skilful erection plays a very important part in the engineering field, and this cannot be too strongly emphasised in order that its true value may be fully realised. A further point which ought to be clearly understood is the close co-operation which should exist between the Designer, Works and Erection Engineer, without which success would be almost impossible.

Most large manufacturing concerns have their own methods for particular operations, but broadly speaking, all erection of Steam Turbine plant must follow similar lines, and it is not intended here to attempt to consider the relative merits of individual methods.

## Foundation and Setting Out of Plant.

It is important that the foundations should be carefully checked, both in respect to datum and actual physical dimensions, etc., before attempting to make a start with the actual erection, since by doing this many minor errors may be obviated at an early stage, and without good foundations no unit will give long-life service.

Assuming then that due care and attention has been given to the construction and checking of foundations, the Erecting Engineer must ensure that the first piece of machinery to be positioned —in the case of the turbine, the exhaust chamber —is carefully set and packed, since this piece forms the key piece for all other settings. The importance attached to this operation will be clear ; without this true basis difficulties are likely to be experienced in obtaining true shaft alignment, to which further reference will be made later.

Large castings are subject to distortion from many causes and must be properly handled when slinging, etc., to avoid distortion. It is therefore necessary to check cylinders not only for levels but also to obviate bore distortion at this early stage, and when the key piece—the exhaust chamber—is accurately erected, then the assembly of the remaining cylinders rarely presents any difficulties

The importance of correctly and firmly packing the various bedplates and pedestal stools for the bearing supports might be mentioned here, since this point is sometimes dismissed as of secondary importance, whereas it is of the utmost importance to ensure that all packings give solid support. Quite apart from the final advantage, this opera-

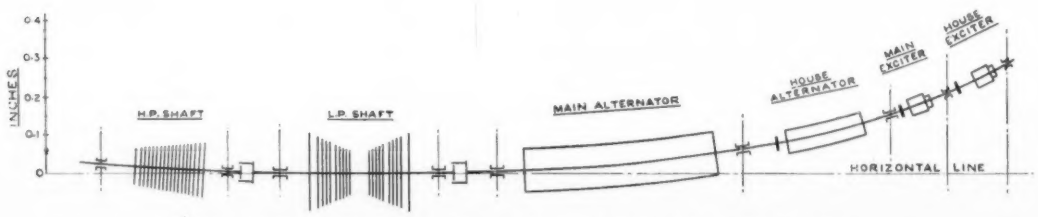


*Fig. 1.—Typical alignment curve for multi-cylinder Steam Turbo Alternator Set.*

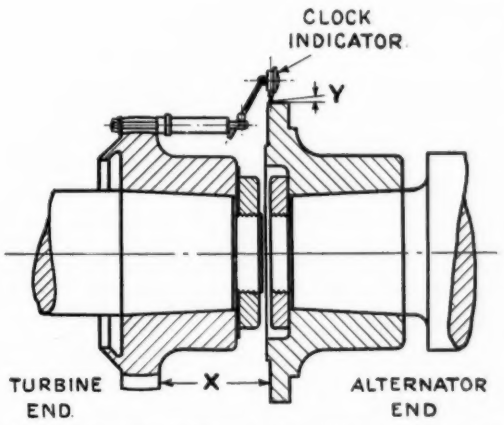


*Fig. 2.—General arrangement of apparatus for measuring coupling alignment.*

tion will ensure that no variation in adjustments and alignment can take place during the erection however much additional weight may be added before final grouting.

Care must also always be taken to see that the jointing up of the condenser to the turbine exhaust and the connecting of the various pipe services to the casings does not produce any undue strains in the latter which will affect the final alignment and running clearances ; also that points of free expansion for cylinders are correctly adjusted.

### Alignment of Shafts.

Having assembled the bottom line of cylinders and bearings, the important operation of lining out the shafts should proceed. To illustrate the requirements Fig. 1 shows a typical shaft deflection curve for the series of shafts of a two-cylinder turbo-alternator set. From this diagram it will be observed that the shafts must be so aligned that they follow the natural deflections of the individual shafts and so form a continuous deflection curve.

These shafts will, of course, always retain their own natural deflections at whatever speed they run, apart from variations when passing through a critical speed, and if this fact is realised, then the appreciation of the importance of alignment follows as a natural sequence.

The fallacy that shafts straighten out under the influence of speed has been conclusively eliminated by theoretical considerations, experiment and practical experience. It follows from the above that the bearings should be lined out to suit the shaft static deflection curve and that the practice sometimes followed of lining out bearings on a horizontal axis is incorrect.

It is not necessary for the Erecting Engineer to know the theoretical deflection curve to obtain satisfactory results, since for all practical purposes true alignment may be obtained by accurate readings taken between the coupling faces and over the coupling periphery, as indicated in Fig. 2.

When equal readings are obtained at four points at 90° to each other round the circumference at points X and Y then the shafts can be taken as being in alignment. This is, of course, assuming the coupling faces and periphery to be true with the journals, and this point must be tested before making any attempt to adjust shafts for alignment. Any error in the truth of the coupling must be carefully allowed for, but since this involves complicated measurements, the obvious thing is for the couplings to be made

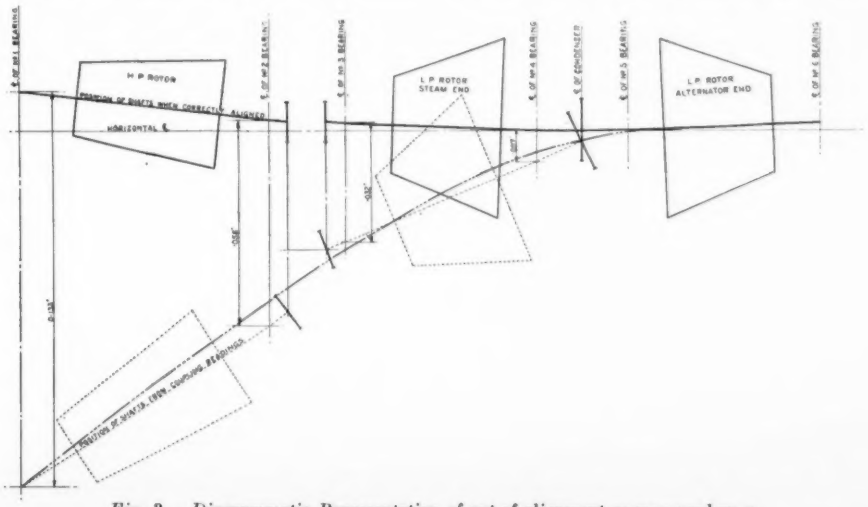


*Fig. 3.—Diagrammatic Representation of out-of-alignment as measured on a 30,000 kW. Multi-Cylinder Turbo Alternator Set.*

| Coupling. | Top. | R.H. | L.H. | Bott. | |
|---|---|---|---|---|---|
| H.P. to L.P. | .0045 | .000 | .0025 | —.002 | Gap reading X as Fig. 2. |
| H.P. to L.P. | .006 | .026 | .021 | .041 | Periphery reading Y as Fig. 2. |
| L.P. to L.P. | .010 | .006 | .006 | .002 | Gap reading X as Fig. 2. |
| L.P. to L.P. | .008 | .006 | .013 | .011 | Periphery reading Y as Fig. 2. |

Measurements recorded are in inches and indicate only relative differences.

true during manufacture, and the most satisfactory method to ensure true faces is to have a reference band turned on both periphery and face after final fitting of coupling to shaft.

The utmost care must be practised in taking readings and the equipment used must be carefully considered. This can be appreciated by a reference to Fig. 3, in which is shown a deflection curve for an actual machine as installed, together with a second curve drawn from measurements obtained at the couplings after some years of service.

The readings from which the displaced curve in Fig. 3 is drawn are given in the Table above, and it is interesting to note that when corrections were made of the order indicated by the vertical displacement disclosed, true alignment was again restored, thus demonstrating the accuracy of the measured readings.

Stress must be laid on this point of accurate readings, as from the two curves in Fig. 3 and the Table of readings it will be seen that the actual errors are relatively small measurements, but the error in shaft alignment as illustrated by Fig. 3 is considerable. In some cases the author has noted careless measurements being made under the mistaken idea that a few thousandths of an inch do not matter, but fortunately such ideas are now almost eradicated. No error of a greater magnitude than .001-in. should be accepted on any set of readings, as by adopting this standard the Erecting Engineer can be assured he will be free from troubles arising from this source.

From the method described and illustrated in Fig. 2, it will be realised that unless the equipment used is carefully designed, considerable sag may occur resulting in completely false alignment, unless a back check is made from each coupling in turn. This is often impracticable due to design of couplings, etc., and it is therefore important that the tool to be used is properly considered, so eliminating any possibility of error from this particular source. It is surprising how often this question of satisfactory tools is overlooked, and reliance placed on the most crude and elementary tackle for such an important job.

It is also not satisfactory to use wedges for measuring between the faces of couplings, since serious errors often occur when this method is used ; only tools of such a type which will permit precise measurements to be made should be used. There are, of course, alternative methods of lining out turbine shafts, but the author is satisfied after many years experience of various methods that measurements over couplings as described reduce the probability of errors to a minimum and permit a high degree of accuracy to be obtained.

The importance of alignment cannot be too widely understood, since the correct alignment of the shafts will influence not only the smooth running of the plant, but will also be largely responsible for the extent of wear and tear on driving parts, such as couplings, bearings, etc.

Excessive wear on flexible or semi-flexible couplings, for example, is nearly always the direct result of faulty alignment. It should be realised that the term flexible or semi-flexible coupling is a description rather loosely used for couplings which are capable of taking up small errors in alignment, but whose primary function is to allow for axial movement between adjoining shafts. Since the magnitude of alignment error they can accommodate is limited, it will be appreciated that mal-alignment must invariably cause coupling wear on the driving faces, however adequate the lubrication may be.

Further, it may be mentioned that the design of the machine as a whole must be given careful consideration throughout with a view to ensuring that true alignment is maintained under actual steaming conditions. It is frequently found, of course, that alignment of machines has altered in service from the original settings due to one of several possible causes, such as foundation settlement, distortion of cylinders, etc., and it is essential always to make a routine check on alignment during periodic overhauls, more especially if heavy coupling wear is evident. To save time during erection or during overhauls at the expense of alignment is indefensible.

### Turbine Clearances.

The setting of blading and other clearances for the rotating parts throughout the turbine forms an important section of erection work, as the designer must rely on the correct adjustment if the design is to fulfil his expectations. Moreover, clearances have also a great influence on the smooth running of the set, and can cause serious and often major failures if not properly adjusted.

To some extent they must be considered at the same time as the shaft alignment, as obviously they are interconnected, the shafts having to be set central in the cylinders and at the same time in true alignment. When carrying out alignment, therefore, the axial blade clearances on impulse

blading must be observed as part of the operation to ensure that the cylinders are not being distorted to obtain alignment at the expense of correct clearances.

Similarly, in the case of reaction turbine blading, the radial clearances must be observed to ensure that the rotors are kept central radially in relation to the cylinder body.

Dealing with blade clearances generally, it will be appreciated that the maintenance of correct clearances is not only essential to reliability, but also to economy in steam consumption.

The same accuracy for identical reasons is necessary when dealing with shaft glands, interstage glands or balancing dummies, and the clearances for these components should be measured by feeler gauges and " leads " to ensure that they are in accord with the design figures.

Bearing clearances should also be given every consideration and attention to ensure that proper bedding and clearances exist. If these points are correctly adjusted, little or no trouble is to be expected from the modern turbine bearing.

Thrust bearings should receive special care in their adjustment to ensure that when shafts are being set the thrust bearing retains its true relationship to the thrust collar and consequently the thrust load is distributed evenly over all pads.

Having dealt carefully with these major items, the machine can be considered ready for final closing up and grouting, although the grouting may be carried out on completion of alignment if preferred.

### Grouting.

The final grouting-in of the various pedestal stools, bedplates, etc., is an operation which requires careful execution, contributing as it does to the general stability of the casing and bearing supports. Although usually carried out by the civil contractors entrusted with the construction of the main foundation block, it should receive the careful supervision of the Erecting Engineer who is conversant with its importance and influence on the running of the set.

The mixture employed, the bonding to the main foundation block and the filling of the inside portions of stools and bedplates where necessary, are among the important points to watch. The regrouting of any defective work is an unsatisfactory operation and it is usual for any defect from any untoward vibration set up to become manifest first at the junction between grout and main block if the foundations become affected.

The operation is one which should be treated as of primary importance, and as playing its full part in the satisfactory operation and life of the set.

### Balance of Rotors.

The balance of the various rotors is also an important matter, but the Erecting Engineer does not often have to concern himself with this problem, since all rotors of a modern turbo-alternator set are carefully dynamically balanced before leaving the manufacturers' works and the technique has attained such a high degree of perfection that very accurate balance of rotating masses is obtained.

The subject is too involved to allow of more than a brief reference in this article, but it should be noted that with the large high-speed units now common, the rotors should be in correct dynamic balance as distinct from static balance if smooth running is to be obtained. The electrical rotors of turbo-alternators sometimes require adjustment to balance after installation, and it is advisable for this to be done by an experienced balancer with suitable apparatus for measuring the magnitude of vibrations.

In earlier days, it was customary to rely on the marking of the rotating shaft with pencils in an attempt to find the out of balance mass, but this was rarely reliable and resolved itself largely into a question of trial and error, and

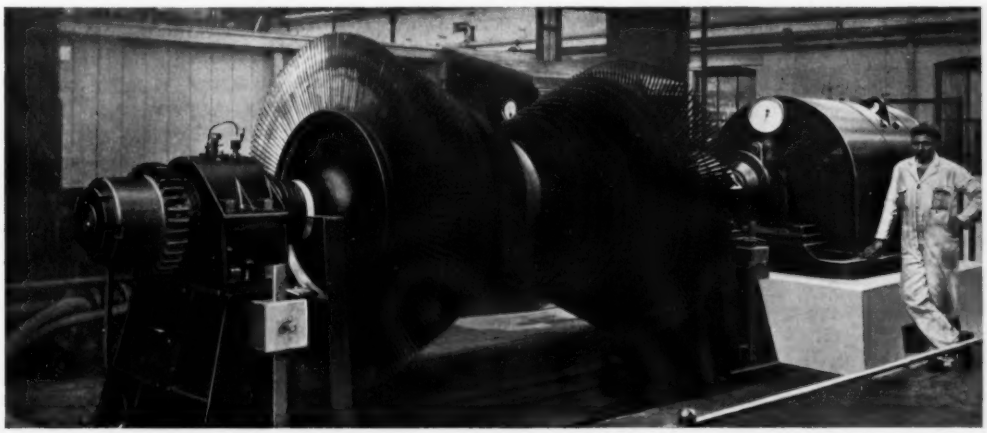

*Fig. 4.—Typical large low-pressure Rotor in Dynamic Balancing Machine.*

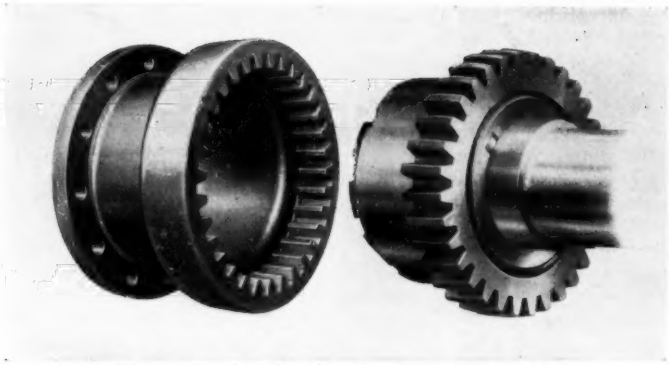

*Fig. 5.—Detail of Flexible Internal Tooth Coupling.*

although reasonably smooth running could be obtained, the method does not ensure correct dynamic balance. This method therefore, has been superseded by more accurate and entirely reliable practice, evolved from a fuller understanding of the subject.

By the use of more accurate precision instruments designed especially for the purpose, good balance can be obtained in a fraction of the time taken by the earlier " hit and miss " method, but unless the Engineer is experienced this is an operation which should not be undertaken by the site Engineer, and never without suitable equipment. It is always advisable to have any rebalancing done by an operator who has made a specialised practice of this work.

In cases where out-of-balance is suspected on steam turbine rotors, these should be returned to the manufacturer's works for accurate checking of the dynamic balance rather than attempting to rely on static balancing, since although it may be permissible to balance a rotor statically for emergency running, it is rarely satisfactory for the continuous smooth running of high-speed rotors.

## General Preparation for Commissioning of Plant.

During the whole of the erection work, attention should be paid to the general cleanliness of the set, and stringent precautions taken throughout to ensure that not only dirt but all extraneous material such as small bolts, screws, borings, etc., are excluded from the machine and all interconnected services. Under present conditions, erection has often to proceed on very exposed sites where building work is also in progress and conditions anything but ideal. Further, the elimination of dirt from the system generally will avoid many of the so-called teething troubles, since many outages in the early life of the turbine plant are due to dirt in one or other of the various systems.

Particular cleanliness is necessary in every part of the lubricating system, as the inclusion of grit or other abrasive material may produce irremedial damage to the bearings, shaft journals, thrust collars and pads and other lubricating surfaces. The modern practice of first circulating a flushing oil is carried out for the dual purpose of removing dirt which can cause such damage, and also to ensure that all impurities are removed which might affect the final charge of turbine oil. Various techniques are used during the flushing operation, but it appears a cardinal principle that the journals should not be rotated until conditions are such that all possibility of dirt passing through them has been eliminated. Time spent on the flushing operations and cleaning the oil system can only be regarded as well spent.

Included in the general preparations are the testing of each separate service, for example, circulating water, condensate and feed system, air extraction, oil system, etc., independently as far as possible. The turbine control gear and emergency devices should also be checked for correct adjustment and operation.

Provided the main requirements outlined above have been attended to and the remainder of the erection work carried out carefully and efficiently, it should be possible to dispense with the long running-up periods previously considered essential on a new plant, and the author has frequently been able by such means to place sets into regular commercial service a few days only after the initial start up.

For similar reasons many years of satisfactory service should also be available with only a normal percentage of outage for periodic maintenance inspection and overhaul, which is ultimately reflected in reduced operation costs.

## Conclusion.

It has not been possible in the space available to deal with any but the most important matters affecting the satisfactory erection of a large turbo-alternator set.

The auxiliary plant, such as condenser, feed heaters, general auxiliaries, etc., all have to be considered in their correct relation, but the principles mentioned apply equally to these components of the plant where applicable.

Enough has been written, however, to show that the Erecting Engineer has an important part to play in the satisfactory commissioning of this class of plant, and deserves every support and assistance which can be given by all other departments and organisations interested in the particular installation.

# The Pumpless Steel-Bulb Mercury-Arc Rectifier.

By J. E. BOUL, A.C.G.I., A.M.I.E.E., Mem.A.I.E.E., Manager, Rectifier Substation Department.

For many years the Mercury-Arc Rectifier has been accepted as an efficient and reliable means of providing a direct current supply from an alternating current source. For low D.C. voltages and for certain special duties, rotary conversion equipment still finds some application but for most industrial and for all traction duties the rectifier has proved its superiority. The widespread adoption of the rectifier in recent years is sufficient testimony to the confidence which is now placed in this type of plant and undoubtedly one of the principal contributions to the growth of rectifier applications has been the introduction of the pumpless steel-bulb rectifier. With the earlier forms of rectifier some hesitation was felt by many engineers in applying this type of equipment. Either the complexity of the vacuum pumping and water-cooling auxiliaries of the pumped steel tank, or the fragility of the glass-bulb rectifier was a deterrent to its adoption. The introduction of the pumpless air-cooled steel-bulb rectifier provided the solution to both forms of criticism, inasmuch that it retains the ruggedness of the pumped steel tank, but avoids the use of auxiliary pumping equipment with its attendant problem of maintenance. Moreover, the pumpless steel bulb can be made for larger outputs than are possible with glass bulbs, thus leading to fewer units for a given kilowatt output.

The English Electric Company has had long experience in the design and manufacture of all types of mercury-arc rectifier ranging from the glass-bulb type of small and medium capacity for industrial application, to the large steel-tank type for heavy duty traction and electrolytic services. Amongst the latter can be counted the largest concentration of rectifier plant in the British Isles in one substation, viz., for an output of 41,000 amperes at 675 volts. Thus it is with a wide background of field experience and careful research that the Company has shaped its technical policy and has maintained its position as one of the leading rectifier manufacturers.

Arising out of this experience and in an effort to provide a small steel-tank rectifier of medium kilowatt capacity suitable for general industrial application, the "English Electric" pumped cubicle-type rectifier was introduced and several were supplied for various service applications. This rectifier proved to be the stepping stone to the pumpless steel bulb and since it exercised such an important influence on the future trend of the Company's design, a consideration of some of its salient aspects will be of interest as a preliminary to a description of the pumpless steel bulb. The rectifier itself was of the side-arm type in which the anode arms projected from the main body of the tank. It was partly air-cooled and partly water-cooled. The water pump, vacuum pumps, water-to-air heat exchanger, and the various controls associated with the circuits supplying these auxiliaries were housed together with the rectifier in a single cubicle to provide a self-contained compact unit. Several departures from previously accepted steel-tank rectifier practice in this country were incorporated in the design of this unit, amongst which may be mentioned the use of air as a medium for the partial cooling of the tank, the general configuration of the vacuum vessel and the use of the soldered porcelain seal for leading insulated electrical connections into the tank. On test and in service this type of rectifier provided some valuable data and experience which later demonstrated the practicability of building a pumpless air-cooled steel bulb. Its ampere output per unit volume of tank was exceptionally high and its ability to maintain a good vacuum over long periods with the vacuum pumps shut off confirmed the view that the use of the soldered seal was a great stride forward in eliminating leakage at the insulated connections in steel-tank rectifiers. When the possibilities of developing a hermetically sealed rectifier vessel of steel became apparent, the obvious advantages accruing from the elimination of the pumping auxiliaries and their control circuits led to the supersedure of the pumped cubicle-type rectifier very shortly after its development.

The evolution of the air-cooled pumpless steel bulb followed rapidly after careful research had established that the materials used in its construction could be produced on a commercial scale consistently homogeneous and free from porosity.

Application of the pumpless steel bulb was made cautiously at first in order to ensure that it would meet all the conditions imposed by service. Several bulbs were installed for various duties and following upon their satisfactory performance over an extended period this type of rectifier was adopted by the Company as a standard type for all but the heaviest duties. At present a large number of bulbs of this type are in satisfactory service in many parts of the world for widely varying duties ranging from normal industrial

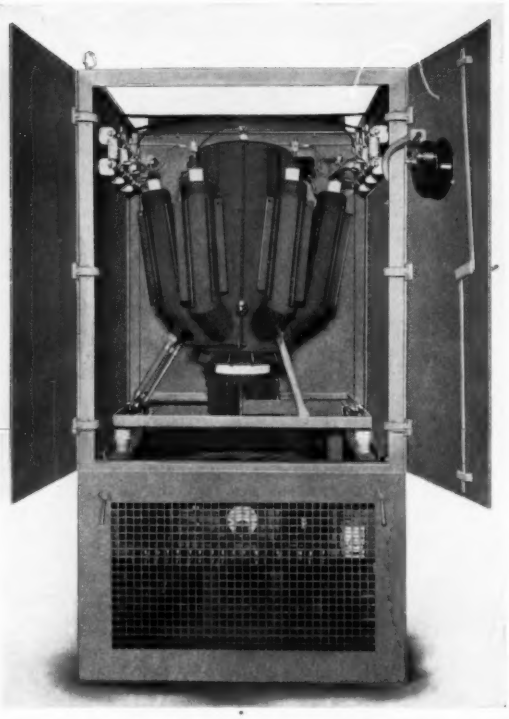

*Fig. 1.—Typical "English Electric" Pumpless Steel-bulb Rectifier Equipment.*

applications at 110 to 600 volts, light and heavy traction duty at voltages of 600 to 1,500 and for special purposes at voltages from 5,000 to 17,000 volts D.C.

Usually the pumpless steel-bulb rectifier is supplied, together with the few auxiliaries it needs, in a sheet-steel cubicle, as illustrated by a typical unit in Fig. 1. It can also be supplied separately as a replacement for glass bulbs. Many such replacements of glass bulbs have been made using the existing cubicle. Fig. 2 is typical of the equipment supplied in such an instance, it includes the bulb and a unit auxiliary panel on which are mounted the excitation auxiliaries suitable for bolting to the cubicle framework.

Several features of the bulb construction are worth noting since they represent considerable improvements over the corresponding features of other forms of rectifier. The use of steel constitutes a distinct advantage in several respects. Its inherent strength and resistance to shock whether in transit, during erection, in service under severe load conditions, or under the abnormal hazards of war are sufficiently obvious to call for no further comments. Again, the fact that a steel bulb can be so readily fabricated without restriction on proportions and that it is not affected in performance by the most severe temperature gradients, gives the designer free scope to design for the optimum efficiency unfettered by considerations of the material being used. The seal used for leading insulated connections into the tank is one which has been well tried in all branches of high vacuum technique over many years. The insulator itself is of porcelain and is soldered into a suitable metal cup on the tank. The soldering process between porcelain and steel is carried out through the medium of a metallic glaze fired into the porcelain. During manufacture this metallic glaze is applied in the form of a colloidal solution. The firing process serves to evaporate the liquid carrier, then to soften the ceramic surface in such a manner that the tiny particles of metal are keyed into place to give a permanent and uniform metallic surface which, at the same time, becomes integral with the insulator.

The method of ignition is illustrated by Fig. 3. It offers a simple and robust means of initiating the excitation arc which overcomes the objections common to practically all other systems. Only one moving part is involved, and this is acted upon downward by the pull of a magnetic solenoid and upward by the restoring force due to the difference in specific weights between mercury and steel. The operation is as follows. When the main incoming A.C. breaker is closed to energise the rectifier transformer and its auxiliary supply

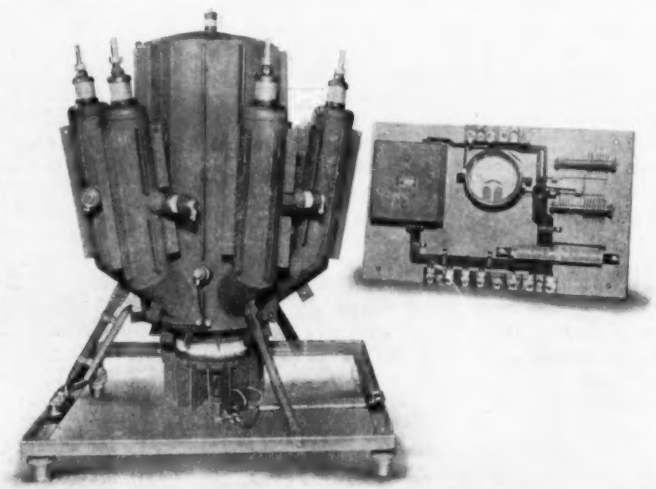

*Fig. 2.—Pumpless Steel-bulb Rectifier and Auxiliary Panel supplied as a replacement for a Glass-bulb Rectifier.*

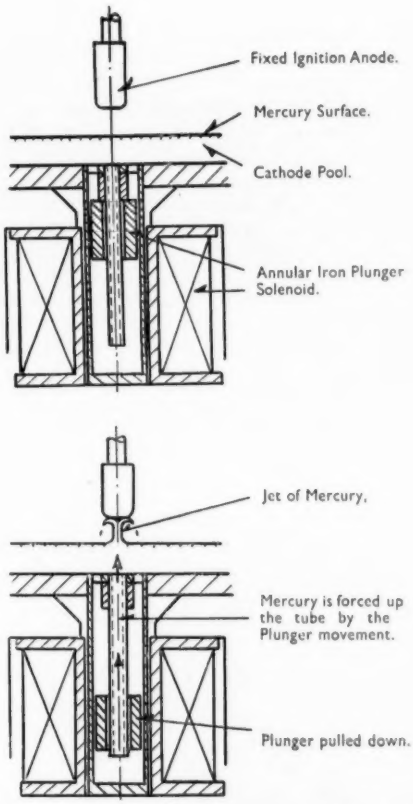


*Fig. 3.—Automatic Ignition system fitted to "English Electric" Pumpless Steel-bulb Rectifiers.*

winding, the external solenoid is energised, the plunger is pulled down and the mercury beneath it is displaced upward through the central tube in the form of a jet which strikes the fixed ignition anode and, in falling away, draws an arc which provides the necessary ionisation to permit the excitation anodes to fire. If, for any reason, the excitation arc is not established on the first ignition "shot" the process is repeated through the medium of the simple excitation relay until the excitation arc picks up. Thereafter the bulb is ready to take load and the ignition solenoid is de-energised. The solenoid plunger is unbreakable and the use of liberal clearances eliminates any possibility of sticking. There are no springs or other moving parts to become fatigued after repeated operations, or as the result of vibration. The solenoid is energised only during the brief interval necessary to the act of ignition.

Before turning to the many applications which the Company's pumpless steel bulbs are serving, it may be well, briefly, to review the conditions under which the mercury-arc rectifier and particularly the pumpless steel bulb, establishes its claims to superiority over other forms of conversion. Efficiency and initial cost are often the prime considerations to be taken into account with such factors as maintenance and attendance costs and general service conditions as subsidiary matters. Dealing with those in the order stated, the dependance of rectifier efficiency upon terminal voltage is well known. The voltage at which the full load efficiency of the rotary convertor and rectifier coincide is dependent upon several factors, and to generalise to the extent of quoting a specific value may be misleading. Furthermore, since few plants operate at or near full load continuously it is important to give consideration to the efficiency/load characteristic of both units. In this connection the rectifier has a pronounced advantage over the rotary convertor when operating at light loads. Thus, for a plant which supplies a small night and week-end load, or which operates intermittently with a low load factor the rectifier is, in practically all cases, the most economical choice.

So far as concerns initial cost the comparison between mercury-arc rectifier and rotary plant follows somewhat similarly the comparisons between their efficiencies, the rectifier generally being cheaper, except at the lowest voltages. Again, so many factors enter into the comparison that it is not possible to generalise to the extent of quoting a specific line of demarcation. In

*Fig. 4.—A bank of eight Pumpless Steel-bulb Rectifiers, aggregate output 2,000 kW., supplying a traction system.*

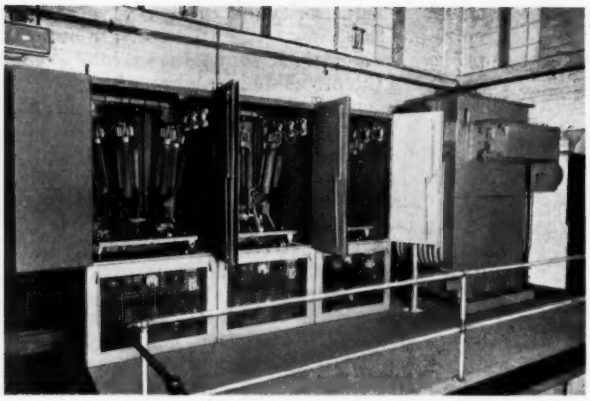

*Fig. 5.—Three Steel-bulb Rectifiers operating in parallel off one transformer, for power supply to a dockyard.*

making the comparison, however, due regard should be paid to the fact that no special foundations are required for the pumpless steel bulb rectifier, beyond a normally level surface, and the floor loading is such that generally no special reinforcement of supported floors is necessary.

On the subject of maintenance and attendance costs, the Company's pumpless steel-bulb rectifier requires no maintenance beyond occasional cleaning of insulators and periodic lubrication of the fan-motor bearings. · It can be operated as normally unattended plant much in the same way as an ordinary power transformer is operated and with very little extra attention. Thus, coming to a consideration of service conditions, it is ideally suited for automatic or remote operated, unattended substations for traction service or as standby plant which, although requiring no attention during extended periods of inactivity is, nevertheless, always ready for immediate service.

Fig. 4 shows a bank of eight pumpless steel-bulb rectifiers having a continuous full load rating of 2,000 kW. supplying a traction system. The eight rectifiers are run in parallel off a single transformer. Three substations on this system of the same kilowatt capacity are equipped with " English Electric " pumpless steel-bulb rectifiers.

Fig. 5 shows an application to a dockyard supply system. In this case three rectifiers are operated in parallel off one transformer. The equipment illustrated typifies the adaptability of this type of plant to existing buildings without the need for expensive floor preparation.

Many other instances could be cited of " English Electric " pumpless steel bulbs supplying traction systems, steel mills, dockyards, hospitals, general workshop services, etc. Apart from such applications at the normal industrial and traction voltages the pumpless steel-bulb rectifier has been successfully applied for special duties at D.C. voltages ranging up to 17,000 volts. Fig. 6 shows a rectifier of this type employing grid control for voltage variation and for high-speed circuit protection. This rectifier is arranged for floor mounting ; the control circuits, etc., being housed in a separate cubicle not shown in the photograph.

" English Electric " pumpless steel-bulb rectifiers are in service in most parts of the British Empire and their reliability has been proved under the most arduous and widely varied conditions. The simplicity of installation and operation, and the rugged nature of its construction makes the pumpless steel bulb particularly suited to situations where skilled labour is not always readily available and where severe handling in transport may be experienced.

*Fig. 6.—17,000 volt D.C. Pumpless Steel-bulb Rectifier with grid control for voltage variation and for high-speed circuit protection.*

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